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(per R. McCullough)
28 Feb 80

The National Bureau of Standards Program

in

Nondestructive Evaluation

NDE

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U.S. DEPARTMENT OF COMMERCE
Institute for Materials Research
National Bureau of Standards
Washington, D.C. 20234

THE NATIONAL BUREAU OF STANDARDS PROGRAM IN NONDESTRUCTIVE EVALUATION

Harold Berger, Program Manager

Institute for Materials Research
National Bureau of Standards
Washington, D. C. 20234

For further information, contact:

Nondestructive Evaluation Program
Materials Building, B354
National Bureau of Standards
Washington, DC 20234

(301) 921-2822

"It is therefore the unanimous opinion of your committee that no more essential aid could be given to manufacturing, commerce, the makers of scientific apparatus, the scientific work of the government, of schools, colleges and universities, than by the establishment of the institution proposed in this bill."

Report on bill to establish
The National Bureau of Standards
May 14, 1900

"The Secretary of Commerce is authorized to undertake the following functions:"

"...development of National Standards"

"...determination of physical constants and properties of materials"

"...development of methods of testing materials"

"...cooperation with other governmental agencies and with private organizations in the establishment of standard practices"

"...advisory service to government agencies"

"...serve special needs of the government"

From Organic Act
March 3, 1901

NONDESTRUCTIVE EVALUATION

A diverse measurement system for the examination of materials or assemblies in any way that will not interfere with their intended use.

FOREWORD

The National Bureau of Standards serves the United States as the authoritative source of accurate, compatible, and useful physical measurements, standards, and information. Since its creation in 1901, NBS has provided the precision measurement foundation for the Nation's science, technology, and commerce.

The basic enabling legislation establishes the main purposes and functions of NBS as follows:

- the development of the national standards of measurement, and the provision of means for making measurements consistent with those standards;
- the determination of physical constants and properties of materials;
- the development of methods for testing materials, mechanisms, and structures and the testing of materials, supplies, and equipment;
- cooperation with other governmental agencies and with private organizations in the establishment of standards, codes, and specifications; and
- advisory service to Government agencies on scientific and technical problems.

The Institute for Materials Research at NBS is concerned with the development of test methods, data and standard reference materials to improve the utilization of materials in the U.S. economy. The

development of advanced materials and energy technologies is demanding greater performance from materials. Thus, there is an increasing need to qualify materials on the basis of performance, not only as produced, but also throughout their lifetimes. Materials testing in the future will rely increasingly on a science-based nondestructive evaluation (NDE) system.

John D. Hoffman
Director
Institute for Materials Research

PREFACE

This booklet provides information about the NBS program in nondestructive evaluation. NDE techniques constitute a diverse measurement system for the examination of materials, components, or assemblies in any way that will not interfere with their intended use. The term evaluation is used to imply that some interpretation of the test data is made to determine usability or useful life. Although related work has long been a part of the NBS program in test methods, materials, and failure analysis, no formal program in nondestructive evaluation was established until 1975. The program serves to coordinate related work throughout NBS and the Program Office serves as a central communication point for NDE developments throughout U.S. industry.

As overall objectives, the program strives to minimize variations in NDE measurements and to develop methods which will facilitate determinations of the useful life of materials, components, and structures under specified conditions. The program makes economic impacts through improved productivity and materials conservation and works to provide a scientific basis for evaluating safety problems.

Though the NDE Program is based in the NBS Institute for Materials Research, it operates Bureau-wide. Program elements span the NBS institutes. In addition to its role as a supporter of specific activities, the program serves to coordinate related work throughout NBS.

We invite comments and suggestions about NDE work. We hope you will find the booklet informative, and urge you to feel free to give us the benefit of your ideas related to NDE problems, methods, and standards.

Harold Berger
Program Manager

CONTENTS

NATIONAL BUREAU OF STANDARDS PROGRAM IN NONDESTRUCTIVE EVALUATION

1. INTRODUCTION

Nondestructive evaluation (NDE) represents a class of industrial inspection techniques used for assessing the integrity of materials or assemblies without impairing their usefulness. NDE tests are designed to reveal the presence of harmful defects such as cracks, porosity, inclusions, and similar inhomogeneities. In addition, NDE methods should detect more subtle inhomogeneities such as those associated with grain size or orientation, internal stress, compositional variations, cold work, and the like, since these variations also may seriously influence the useful life of the component. In each case, the goal of the NDE test must be to identify the inhomogeneity in terms of size and location. In this way, the influence of the defect on materials performance can be reliably assessed.

Nondestructive measurements yield information useful for:

- eliminating defective materials prior to expensive machining or fabrication,
- assessing the condition of parts or assemblies during and after fabrication,
- determining the condition of materials or assemblies after a period of use,
- monitoring to detect signs of failure during operation, and
- aiding effective failure analysis to minimize future failure problems.

NDE has a strong impact on productivity, materials and energy conservation, as well as safety.

The NDE methods commonly used in industry include ultrasonics, radiography, visual-optical tests, eddy currents, penetrants, and magnetic particles. The methods tend to be complementary. Therefore, it is not unusual to find more than one method used to inspect an object. Visual-optical and penetrant methods are useful for the inspection of surfaces and surface-connected defects. Magnetic particle and eddy-current techniques can reveal surface and shallow defects in ferromagnetic and electrically conducting materials. Radiography and ultrasonic methods are capable of probing deeply into various materials and structures. Radiography offers advantages for confirming part placement in complex structures. Ultrasonic methods tend to be sensitive for the detection of cracks. A comparison of the common NDE methods is given in Table 1.

A gamma radiograph of the Liberty Bell, taken before it was moved to its Bicentennial location. (Courtesy, Eastman-Kodak Co.)

Table 1. Comparison of common nondestructive evaluation methods.

Method	Characteristics detected	Advantages	Limitations
Ultrasonics	Changes in acoustic impedance caused by cracks, nonbonds, inclusions, or interfaces.	Can penetrate thick materials; excellent for crack detection; can be automated.	Requires coupling to material either by contact to surface or immersion in a fluid such as water.
Radiography	Changes in density from voids, inclusions, material variations; placement of internal parts.	Can be used to inspect wide range of materials and thicknesses; versatile; film provides record of inspection.	Radiation safety requires precautions; expensive; detection of cracks can be difficult.
Visual-Optical	Surface characteristics such as finish, scratches, cracks or color; strain in transparent material.	Often convenient; can be automated.	Can be applied only to surfaces, through surface openings or to transparent material.
Eddy Current	Changes in electrical conductivity caused by material variations, cracks, voids, or inclusions.	Readily automated; moderate cost.	Limited to electrically conducting materials; limited penetration depth.
Liquid Penetrant	Surface openings due to cracks, porosity, seams or folds.	Inexpensive, easy to use, readily portable, sensitive to small surface flaws.	Flaw must be open to surface. Not useful on porous materials.
Magnetic Particles	Leakage magnetic flux caused by surface or near-surface cracks, voids, inclusions, material or geometry changes.	Inexpensive, sensitive both to surface and near-surface flaws.	Limited to ferromagnetic material; surface preparation and post-inspection demagnetization may be required.

2. OBJECTIVE OF THE NBS PROGRAM IN NONDESTRUCTIVE EVALUATION

The objective of the Nondestructive Evaluation (NDE) Program is to improve the reliability of materials and structures through standardized NDE measurement procedures. The role of NBS is to help industry develop methods for accurate and reproducible NDE measurements. This includes technical investigations of standards (both physical calibration standards and procedural documents such as recommended practices), characterization of instruments, development of improved techniques, and the assessment of the meaning of the NDE measurement on material performance.

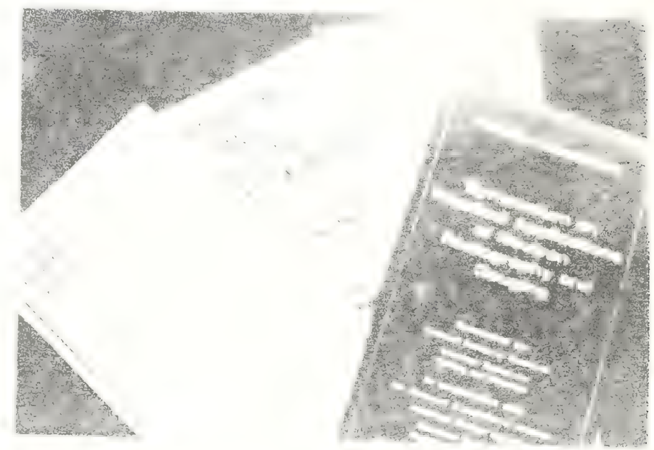
To accomplish this objective, a program related to NDE standards, procedures, and technology has been established. A description of the technical program is given in Section 4.

NDE PROGRAM

will help determine } Material reliability, Material performance

by } Standards, Procedures, Technology

In addition, strong interactions with industry, technical societies and government agencies have been established in order to solicit input on needs and to aid in technology transfer for developed methods and standards. Effective technology transfer requires NBS participation in meetings and NBS meeting sponsorship. Brochures from several recent NBS meetings related to NDE are pictured.



Brochures for several recent NDE meetings at NBS.

3. PROGRAM PLAN

A. Medium Range (1-5 years)

The Nondestructive Evaluation Program is emphasizing the needs for improved measurement and calibration standards and procedures for the six common methods used in industry (visual-optical, magnetic

particle, ultrasonic, penetrant, radiographic, and eddy current). This emphasis will help bring these methods to a point where measurements can be made in a more meaningful and reliable manner. Reproducibility of measurements will be improved; calibrations will have better traceability.

Although the emphasis is as indicated during this period, work to better understand materials performance and to develop other NDE methods will also be initiated.

B. Long Range (beyond 5 years)

Once the NDE Program has addressed the basic measurement problems of the six major methods, there will be two significant remaining tasks. The major one is to relate material behavior to NDE indicators so that the performance of materials under both new and in-service conditions may be reliably predicted. To do this the NDE technology must be capable of quantitative and reliable flaw detection. In addition, the non-destructive measurement of material properties such as hardness or residual stress will also have to be accomplished. Therefore, a second major task is the development of additional NDE methods for material property measurements.

The successful accomplishment of these tasks will fill future needs now becoming apparent. The NDE profession must develop methods that are more reliable and accurate in relating flaw and material property measurements to the performance of materials and components. Above all, this requires a shift from qualitative to quantitative measurements combined with the analytical tools to make accurate failure prediction estimates. The improved measurement and reliability capability accomplished early in this program will contribute to that need, as will the development of methods for the determination of material properties.

In the long term these program objectives will lead to significant savings by helping to make realistic material and performance specifications a reality.

4. THE PRESENT TECHNICAL PROGRAM IN NDE

A. Acoustic-Ultrasonic Programs

Work is in progress to develop methods for calibration of ultrasonic and acoustic emission transducers. Spectral characteristics, beam profile and total sound power measurements are being addressed. A transducer calibration service is available; plans include an expanded service.

Ultrasonic test blocks are under study in a program partially funded by the Air Force, Army, and the National Aeronautics and Space Administration to determine the reasons for variability of these metal calibration blocks. Further directions for this effort include the development of material-independent test blocks and the development of well-characterized fatigue cracks that could serve as a calibration for many NDE tests. In the near term, sets of calibrated aluminum test blocks will be available on a loan basis.

Instrumentation development work in both ultrasonics and acoustic emission is also in progress. This includes development of improved signal to noise ratio systems by methods such as signal averaging and pulse compression. A program to characterize the important variables in ultrasonic instrumentation has recently started. Imaging instrumentation is also under development.

Application of these NDE methods is being made to metals, ceramics, polymers, and building materials.

Specific application studies involving advanced ultrasonic instrumentation are also being conducted for the U.S. Nuclear Regulatory Commission (for steel reactor components) and the National Institutes of Health (ultrasonic diagnostic equipment for cancer detection).

A program to develop a theoretical basis for acoustic emission spectral analysis to characterize moving cracks or defects has recently started, partially funded by the Electric Power Research Institute. This program includes work for improved transducer calibration. In this program the theory to predict the acoustic emission spectral characteristics expected to be emitted by a moving defect will be developed and verified by experimental work in both transparent [illegible] participation with standards and code development groups, particularly the ASTM and ASME.

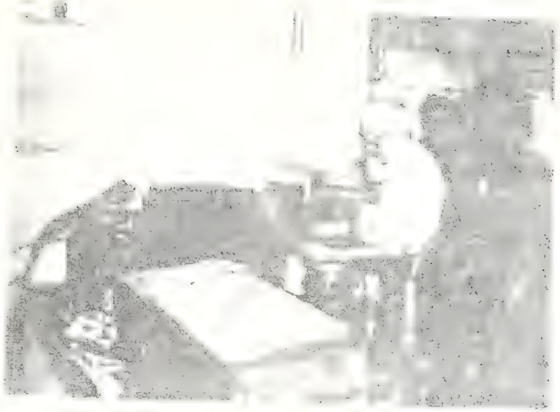
Large porcelain insulators are tested by acoustic emission.

Current programs involve work in both neutron and x-radiography. The x-ray program includes investigations of standards for the measurement of spatial resolution in radiographic systems (with initial emphasis on methods for determining radiographic unsharpness) and for the characterization of real-time fluoroscopic systems. Developments in progress include work on improved x-ray screens and grids, determination of scattered radiation content and its effect on radiographic detectors, and a scattered radiation approach to x-ray inspection that would permit such inspections to be accomplished from one side.

[illegible] neutron radiographic studies [illegible] marily with a thermal neutron radiographic facil[illegible] the NBS Research Reactor. Work has been done with a 3 MeV Van de Graaff accelerator and a 100 MeV linear accelerator; a Californium-252 source is also avail[illegible] [illegible]ended practice for thermal neutron radiography is being developed in collaboration with ASTM Committee E-7.05, Neutron Radiography. Standards [illegible]

[illegible] intensity and energy [illegible] size and uniformity, and [illegible] divergence. Development work has concentrated on [illegible] systems, convenience and alignment methods such as Polaroid film and radiographic paper, improved neutron conversion screens and gas-cell detectors.

Application feasibility studies and special technique developments are also undertaken. An example of the latter is work to demonstrate three-dimensional thermal neutron radiography in collaboration with Argonne National Laboratory.



Beam facility at the thermal column of the NBS Reactor is used for neutron radiography.

Electromagnetic [illegible]

a. Visual

A program recently initiated will examine methods for the measurement of visual acuity under typical NDE inspection conditions. This will include consideration of subdued lighting common in radiographic reading rooms and the dark booth situations typically used in fluorescent penetrant and magnetic particle inspection.

The program will characterize test methods used in NDE where the human eye is an integral part of the system. Visual parameters critical to the ability of people to detect and judge visual indications of defects will be identified. These accomplishments will lead to recommendations for improved visual acuity measurement methods.

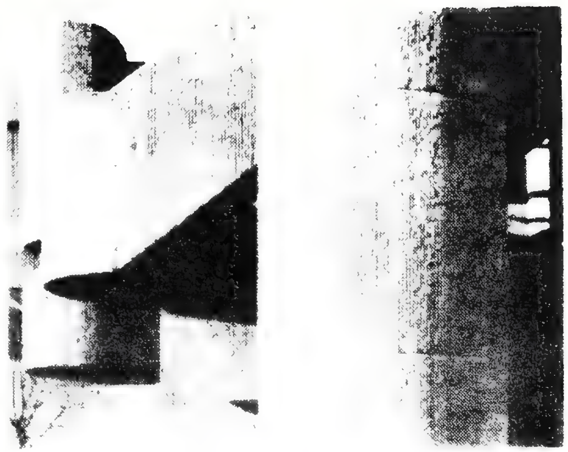
b. Electrical, [illegible]

Facilities for DC electrical conductivity measurements are essentially complete as the first stage of a new program in electrical and eddy-current methods. An AC conductivity measurement facility is also planned. Future directions for this work include the establishment of measurement procedures for conductivity standards over the range 1-100% IACS and methods for the calibration of eddy-current test equipment.

[illegible] electrical conductivity.

c. Microwave [illegible]

Microwave [illegible] are being used to determine physical properties of materials. A new part of the NDE Program utilizes microwaves to measure moisture content of concrete. These measurements will be related to the strength of the material. This represents one area in which NDE methods are being explored for applications in the building industry. Future work to measure moisture content of other building materials is planned.



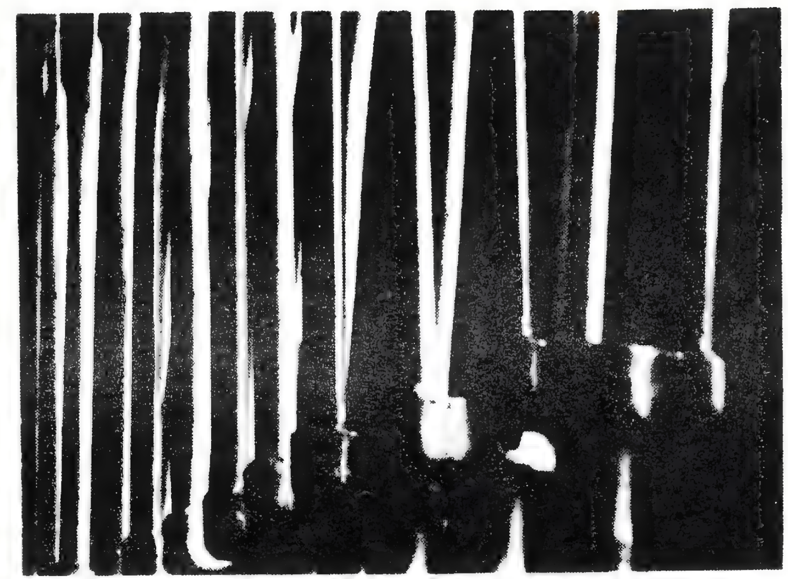
Microwave measurements may impact concrete structures such as these.

D. Penetrant Testing

An investigation of the feasibility of preparing a master crack calibration plate for the evaluation of penetrant sensitivity is beginning. It is proposed to electrodeposit a heavy, non-adherent layer of nickel over a suitable crack plate and to use the removed nickel master to prepare duplicate calibration plates.

It is known that this method will accurately reproduce crack dimensions as small as 3 μm wide by 3 μm deep. Methods for reproducing smaller dimensions are under study.

If the method proves useful, then the nickel master plate could be very well characterized. The calibration plates produced from it could be relatively inexpensive and could be discarded after some period of use. This would minimize problems presently encountered concerning the uncertainty of crack size due to crack growth and/or cleaning difficulties.



Bicycle forks were tested with penetrants to detect dangerous cracks.

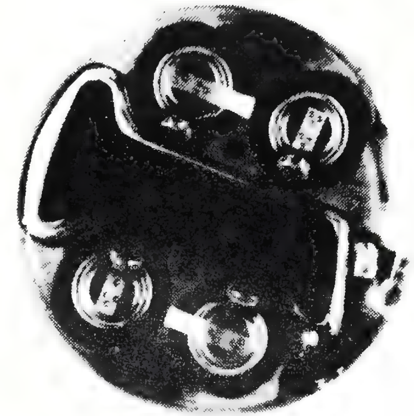
E. Wear Debris Analysis

Detection of worn metal in lubricants in mechanical machinery is now used in both military and civilian programs to determine the proper time for engine, bearing, and transmission overhaul. This method is now being expanded in a current NBS program (partially funded by the U.S. Navy) in which the wear debris particles in the lubricant are detected, sized, and examined in order to determine where and by what mechanism wear is occurring. Magnetic methods for obtaining size distributions of wear particles are used. X-ray microanalysis techniques have been developed for particles in the micrometer range. The techniques offer increased sensitivity for engine condition monitoring compared to conventional SOAP methods.

Different forms of wear debris particles recovered from oil.

F. Thermal

A newly initiated program proposes to develop a method for the nondestructive evaluation of batteries used in critical assemblies such as cardiac pacemakers. A microcalorimeter capable of measurements in the 0.2 to 1000 microwatt range will be used to measure heat generated in batteries and, in some cases pacemakers, under a variety of conditions. Heat generation by new and partially discharged batteries will be measured under no-load conditions as a measure of self-discharge. A high rate of self-discharge would indicate short shelf life and may indicate short duty life. Heat generation will also be measured under load conditions. It is anticipated that the work will be done in combination with other nondestructive and destructive tests and will result in a nondestructive method to determine power cell quality.

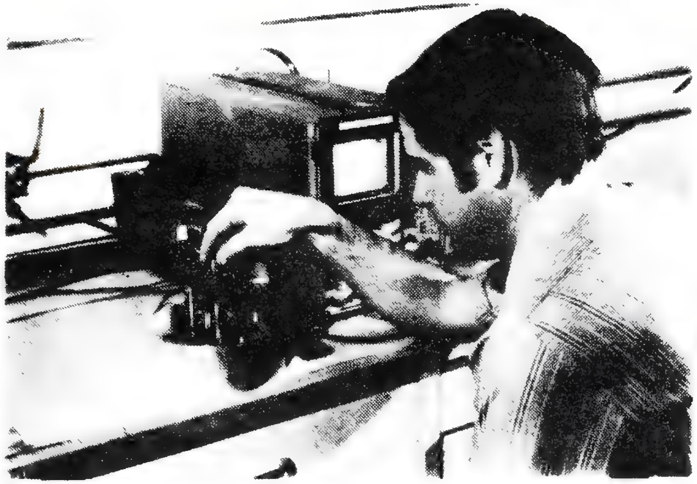


Cardiac pacemaker with four batteries.

5. SOME RECENT SIGNIFICANT ACCOMPLISHMENTS

A. Calibration Procedures for Acoustic Emission Transducers

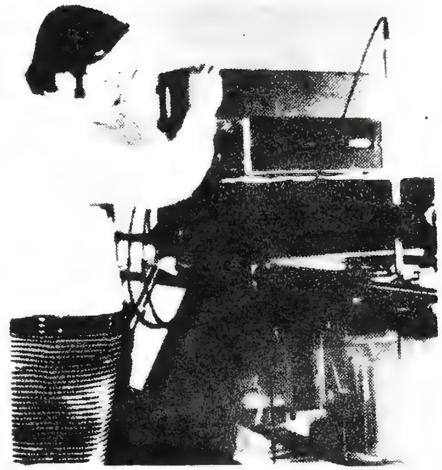
In order to understand the meaning of acoustic emission signals it is necessary to determine the intensity, timing and spectrum of the emissions. To accomplish that one must know the spectral response of the transducer used for detection. A new method for calibrating acoustic emission transducers has been proposed by NBS. The method is based on a comparison of the actual response of the transducer to the theoretical response from a step function of stress. The theoretical response has been confirmed experimentally using a breaking glass capillary tube as the emission source. Work is now in progress to replace the aluminum transmission block used in proving the method with a large steel block that will be more representative of a typical reactor measurement problem. The steel block tests will serve to assist ASME Code Committees in deciding on a recommended method for transducer calibration. A limited acoustic emission transducer calibration service is planned.



Transducer response to an impulse is obtained.

B. Ultrasonic Reference Block Measurements

Cylindrical metal blocks containing flat bottom holes are used to calibrate ultrasonic test equipment. There has been appreciable variability in these blocks and the resulting calibrations. An NBS program, partially sponsored by the Air Force, Army, and NASA, has been underway to determine the primary causes of this variability. A representative data base for aluminum test blocks has been established. Metallurgical variations, some remaining from ingot solidifications, have been shown to account for the major part of the observed variability, some of which has been shown to be as great as 800%. Replicate blocks from one batch of aluminum have been fabricated at NBS and show variations in ultrasonic response of less than 10% through a frequency of 10 MHz. This compares with an average variation of $\sim$ 30% for field blocks. Plans are to establish a loan service for calibrated reference blocks.



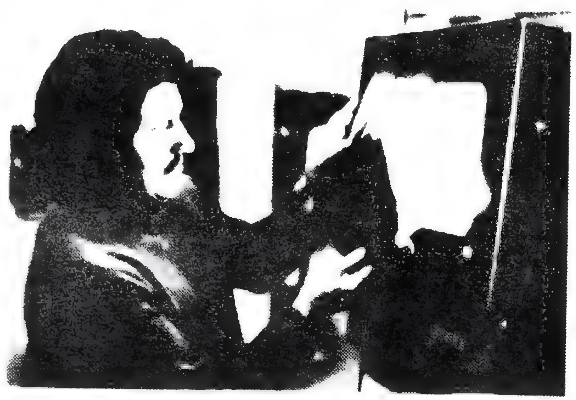
Ultrasonic calibration blocks are tested in an immersion tank.

C. Pulse Compression Methods for Ultrasonic Inspection

One of the present problems in ultrasonic inspection is the difficulty of putting sufficient pulsed ultrasonic power into an attenuating specimen (such as a stainless steel reactor component) to be able to detect a reflection signal from an internal discontinuity. One method for accomplishing this is to spread the ultrasonic pulse over a longer time so more power may be put into it. If the received pulses can then be compressed in time so that they retain the high signal level and, in addition, are capable of resolving closely spaced discontinuities, then a significant improvement in ultrasonic testing will have been realized. This pulse compression technique, which is used extensively in chirp radar systems, has now been successfully applied at NBS to ultrasound NDE. A compression factor of 7:1 has been achieved and work is in progress to extend it to 20:1. Ultimately, pulse compression ratios exceeding 100 should be achievable.

D. Three-Dimensional Thermal Neutron Radiography

It is difficult to separate out depth information from radiographic inspection results and complex objects are difficult to inspect by radiography because of the many overlaying shadows. The separation of radiographic images from individual object planes can overcome these problems. Methods for performing this three-dimensional radiography with thermal neutrons have recently been demonstrated. A multiple-film laminagraphy method, utilizing as many as 9 individual thermal neutron radiographs taken over a 40° angular coverage, has been shown to provide a spatial resolution of 0.25 mm for an object thickness of 6 cm. Tests were made on several test objects and on a simulated fast reactor fuel subassembly to demonstrate applicability. Tests were made at the NBS Research Reactor in collaboration with Argonne National Laboratory.



Neutron radiographs are placed for three-dimensional viewing.

6. TABULAR SUMMARY OF NBS PROGRAM IN NDE

	Technique	Principle Investigators
A.	Acoustic-Ultrasonic	
	Acoustic Emission Theory	J. A. Simmons and R. B. Clough
	Application to:	
	Building Materials	J. R. Clifton
	Inorganic Materials	E. R. Fuller, M. Linzer, and E. Rockar
	Metals	J. A. Simmons and N. Hsu
	Polymers	E. A. Kearsley
	Reactor Materials	D. G. Eitzen, N. Hsu
	Crack Characterization	D. J. Chwirut, D. G. Eitzen, and A. W. Ruff
	Instrumentation Characterization	N. T. Larsen
	Instrumentation Development	M. Linzer
	Transducer Calibration	F. R. Breckenridge, C. E. Tschiegg, and M. Greenspan
	Ultrasonic Test Blocks	D. G. Eitzen and C. J. Bechtoldt
B.	Radiography	
	Neutron Radiography	H. Berger and D. A. Garrett
	X-Radiography: Real-time systems, Unsharpness measurements	J. W. Motz

	Scatter Investigations	C. E. Dick
	Screen Characterization	R. C. Placious
C.	Electromagnetic Methods	
	Visual Acuity Standards	G. Yonemura
	Electrical, Eddy-Current	G. M. Free and N. B. Belicki
	Microwaves	W. E. Little
D.	Penetrants	
	Crack Standard Development	F. Ogburn
E.	Wear Debris Analysis	
	Particle Detection, sizing and evaluation	A. W. Ruff and L. K. Ives
F.	Thermal tests	
	Battery Characterization	E. J. Prosen

7. SOME RECENT NBS PUBLICATIONS IN NDE

Included in this list are publications from several NBS programs with a strong connection to NDE. Examples of other program areas from which publications are taken include Remote Sensing (Boulder) and Electronic Technology (Gaithersburg).

Publications are listed with general topics first, then following the order in which topics were discussed, and finally, adding publications from associated work.

"A Review of Nondestructive Evaluation Opportunities," R. M. Thomson, Standardization News, 3 [3], 8 (1975).

"Nondestructive Measurements - How Good Are They?", H. Berger, Materials Evaluation, 34 [1], 18A (1976).

"Acoustic Emission: Some Applications of Lamb's Problem," F. R. Breckenridge, C. E. Tschiegg, M. Greenspan, J. Acoustical Soc. of America, 57 [3], 626 (1975).

"Improved Ultrasonic Standard Reference Blocks," D. G. Eitzen, G. F. Sushinsky, and P. J. Chwirut, NBSIR 75-685 (1975).

"Application of Ion Beam Milling to the Characterization of Cracks in Metals," NBS Technical Note 862 (1975).

"Proof Testing of Porcelain Insulators and Application of Acoustic Emission," A. G. Evans, S. M. Wiederhorn, M. Linzer, and E. R. Fuller, Jr., Ceramic Bull. 54, 576-80 (1975).

"The Effects of Specimen Size and Microstructure on the Larson-Miller Parameter," R. B. Clough, Scripta Metallurgica, 9, 1325-29 (1975).

"Acoustic Emission and Crack Propagation in Polycrystalline Alumina," A. G. Evans, M. Linzer, and L. R. Russell, Materials Sci. and Eng. 15, 253-61 (1974).

"Calibration of Quartz Transducers as Ultrasonic Power Standards by an Electrical Method," T. L. Zapf, IEEE Ultrasonics Symposium Proceedings, 45 (1974).

"Pyroelectricity and Piezoelectricity in Oriented Films of Polyvinylfluoride and Polyvinylidene Fluoride in Electrets, Charge Storage and Transport in Dielectrics," (ed.: M. M. Perlman), the Electrochemical Soc., Inc., Princeton, N. J. (1973), p. 505-516.

"Failure Prediction in Structural Ceramics Using Acoustic Emission," A. G. Evans and M. Linzer, J. Am. Ceram. Soc. 56, 575-81 (1973).

"Practical Applications of Neutron Radiography and Gaging," (ed.: H. Berger), ASTM-STP 586, Am. Soc. for Testing and Materials, Philadelphia, Pa. (1976), 320 pp.

"Radiographic Nondestructive Testing," H. Berger, Standardization News, 3 [3], 21-29 (1975).

"X-Ray Scatter Background Signals in Transmission Radiography," J. W. Motz and C. E. Dick, Medical Physics, 2 [5], 259 (1975).

"A Qualitative Discussion of Quantitative Radiography," in The Role of Nondestructive Evaluation, H. Berger and J. W. Motz, No. 5 in the Materials/ Metal Working Technology Series, Am. Soc. for Metals (1975), p. 37.

"An Evaluation of Radiographic Paper for Thermal Neutron Radiography," H. Berger, Trans. Am. Nuclear Soc. 21, 148-149 (1975).

"Standard Reference Materials: The Eddy-Current Decay Method for Resistivity Characterization of High Purity Metals," A. F. Clark, V. A. Deason, J. G. Hunt, and R. L. Powell, NBS Special Publication 260-39 (1972).

"Metallurgical Analysis of Wear Particles and Wearing Surfaces," A. W. Ruff, NBSIR 74-474 (1974).

"Microcalorimetry Applied to Biochemical Processes," J. Prosen, R. N. Goldberg, R. R. Staples, R. N. Boyd, and G. T. Armstrong, in *Thermal Analysis: Comparative Studies on Materials* (eds.: H. Kambe and P. D. Garn), J. Wiley, New York (1974), pp. 253-289.

"Summary of the American Nuclear Society Topical Meeting, Nondestructive Testing in the Nuclear Power Industry," H. Berger, Nuclear News, 18 [1], 68-74 (1975).

"Semiconductor Measurement Technology: Improved Infrared Response Technique for Detecting Defects and Impurities in Germanium and Silicon p-i-n Diodes," A. Sher, NBS Special Publication 400-13 (1975).

"Nondestructive Tests to Determine Concrete Strength - A Status Report," J. R. Clifton, NBSIR 75-729 (1975).

"A Summary of the Conference on Emerging Techniques for Nondestructive Field Testing - Opportunities for NDT in Transportation," H. Berger, Materials Evaluation, 33 [7] (1975).

"Fracture Mechanics and Its Application to Cryogenic Structures," H. I. McHenry, International Cryogenic Materials Conf., Kingston, Ontario (1975).

"Laser Scanning of Active Semiconductor Devices," D. E. Sawyer and D. W. Berning, Tech. Digest, International Elec. Dev. Meeting, IEEE, Washington, D. C. (December 1-3, 1975).

"Semiconductor Measurement Technology: ARPA/NBS Workshop II. Hermeticity Testing for Integrated Circuits," H. A. Schafft, NBS Special Publication 400-9 (1974).

"Mössbauer-Effect Examination of Ferrite in Stainless Steel Welds and Castings," L. J. Swartzendruber, L. H. Bennett, E. A. Schoefer, W. T. Delong, and H. C. Campbell, Welding Journ. (1974).

"A Metallurgical Basis for the Non-Destructive Wire-Bond Pull Test," G. G. Harman, 12th Annual Proc. IEEE Reliability Physics, 205-210 (1974).

"State of the Art on Durability Testing of Building Components and Materials," L. W. Masters, W. C. Wolfe, W. J. Rossiter, Jr., and J. R. Shaver, NBSIR 75-132 (1973).

"A Laser Technique for Investigating the Effects of Thermal Transients on Pressure Transducer Performance Characteristics," NBS Technical Note 723 (1972).

"Retrieved Austentite Developed During Surface Grinding of a Carbon Steel," L. J. Swartzendruber and L. H. Bennett, Scripta Metallurgica 6, 737-742 (1972).

"Mössbauer Scattering: Promise and Limitations as a Quantitative Metallographic Tool for Steels," L. H. Bennett and L. J. Swartzendruber, International Conf. Applications of the Mössbauer Effect, Ayeleth-Hoshahar, Israel (August 28-31, 1972).

"Martensite Transformation Detection in Cryogenic Steels (Magnetometer Development)," F. R. Fickett, NBS Technical Note 613 (1971).